THE EFFICACY OF USING FILTERED DICHOTIC WORDS TO DETECT SUBTLE AUDITORY PROCESSING ISSUES IN YOUNG ADULTS

Capstone Project

Presented in Partial Fulfillment of the Requirements for

the Doctor of Audiology

in the Graduate School of The Ohio State University

By

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The Ohio State University
2011

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ABSTRACT

The aim of the present study was to determine whether the use of a dichotic speech recognition task was sensitive to the auditory processing complaints of young adults. Subjects were 24 normal-hearing young adults, aged 19 to 38 years (mean = 23.5 years). Ten subjects with no auditory processing complaints and normal scores on the SCAN-3:A (Keith, 2009) comprised the normal control group. The remaining 14 subjects presented with auditory processing complaints and had normal to borderline performance on the SCAN-3:A, placing them in the probable APD group. Dichotic word recognition performance was examined across three response conditions: free recall, directed right, and directed left, in both an unfiltered and filtered condition. The results of this study revealed no significant difference between these groups in terms of performance on the filtered dichotic word recognition task. However, when subjects in the probable APD group were divided into two different groups (APD I and APD II) according to their SCAN-3:A scores, a significant difference in performance was found between the normal control and the APD II group. These results suggest that the SCAN-3:A normative data for young adults may be inappropriate for classifying patients in this population as normal or disordered. The lack of significant difference in performance between the probable APD group and the normal control group is likely due to the large amount of variability in performance among subjects in the former group.

DEDICATION

I would like to dedicate this document to my parents, Donald and Roberta Lamoreau. Their lasting support throughout my life and particularly during college and graduate school is one of the main reasons I have succeeded in my academic career. They have always believed in me and have never been afraid to show it. They have supported me even through the most difficult of decisions and I credit them for who I am today. I love you both.

I would also like to dedicate this document my boyfriend, Jordan Duncan, particularly for his support during this uniquely difficult third year of my Doctor of Audiology program. He has had the unfortunate pleasure of living with me during a year in which I have had to write my third year exams, find a fourth year placement, and complete an entire capstone, among other things. Thank you for keeping me sane, and not letting me drive you crazy. I love you. Also, thanks for keeping Opie from eating my capstone.

This document is also dedicated to all of the friends who have supported me throughout my academic career. Thank you for being understanding when I have had to lock myself in my room to write several pages of my capstone rather than doing something fun. I am especially grateful to Cally Ellis, Helen Foster, Gina Crough, and Stephanie Wedryk for their support.

ACKNOWLEDGMENTS

I would like to thank Dr. Christina Roup for all of her help and attention during the process of completing this study. She has made herself readily available to me for hours at a time to answer questions and provide pep talks when I was feeling particularly frazzled. Your attention to detail and belief in my abilities has made this study a success. Thank you very much!

I would also like to thank the wonderful audiology faculty in the Department of Speech and Hearing Science at the Ohio State University. The knowledge that these individuals have bestowed upon me provided me with a strong foundation on which build this study.

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LIST OF ABBREVIATIONS

AAA	American Academy of Audiology
ADHD	Attention Deficit Hyperactivity Disorder
APD	Auditory Processing Disorder
ASHA	American Speech-Language-Hearing Association
CHAPPS	Children’s Auditory Processing Performance Scale
CANS	Central Auditory Nervous System
CV	Consonant-vowel
CVC	Consonant-vowel-consonant
LEA	Left Ear Advantage
MAPA	Multiple Auditory Processing Assessment
REA	Right Ear Advantage
SSW	Staggered Spondaic Word

CHAPTER ONE

Introduction

Dichotic listening is a speech recognition task in which simultaneously presented stimuli (words, digits, sentences, etc.) differ across the ears, and the listener is required to repeat one or both of the stimuli heard (Keith & Anderson, 2007). Dichotic listening enhances the functional asymmetry of the central auditory system, where contralateral pathways are considered to be stronger than ipsilateral pathways (Sparks & Geshwind, 1968; Studdert-Kennedy & Shankweiler, 1970; Rasmussen & Milner, 1977). Because of the relative strength of the contralateral pathways of the auditory system, words presented to the right ear have the most direct pathway to the left hemisphere, thought to be responsible for the processing of speech information (Dirks, 1964; Kimura, 1967). As a result, for most normal-hearing young adults, a greater number of speech stimuli are correctly reported from the right ear, as compared to those stimuli correctly reported from the left ear, reflective of the dominance for language attributed to the left hemisphere (Keith & Anderson, 2007). This is known as the right ear advantage, or REA (Kimura, 1967).

Because the REA, generally small in magnitude, has been consistently demonstrated in normal-hearing young adults throughout the literature (Dirks, 1964; Noffsinger, Martinez, & Wilson, 1994; Wilson & Jaffe, 1996; Wilson & Leigh, 1996;

Strouse & Wilson, 1999; Roup, 2011), it is considered the standard for normal performance on dichotic listening tasks. Abnormal performance on dichotic listening tasks, demonstrated by poor overall performance, or an abnormally large REA (also known as a left ear deficit), is consistent with abnormal auditory processing as a result of delayed maturation of or damage to the auditory system (Wilson & Jaffe, 1996; Roup, 2011, Keith & Anderson, 2007). Thus, dichotic listening can be used as a measure of the integrity of the central auditory system, based on the comparison of a patient's performance to normative data (Keith & Anderson, 2007).

Clinically, dichotic listening can be used to determine the presence of binaural interference, a phenomenon in which binaural stimulation is found to be detrimental to speech understanding, and speech recognition skills are significantly poorer in the binaural condition as compared to the monaural condition (Jerger et al., 1993). Dichotic speech recognition represents a valuable clinical tool for determining hearing aid outcomes in the older adult population, given that an estimated ten percent of those older adults seen in audiology clinics have binaural interference issues secondary to the aging of the auditory system (Jerger et al., 1993). Chmiel et al. (1997) and Carter, Noe, and Wilson (2001) presented case studies which found significant left ear deficits on dichotic listening tasks in individuals who exhibited little binaural hearing aid benefit and a preference for a monaural hearing aid fitting. The results of these studies suggest that the use of a dichotic listening task prior to a hearing aid fitting can predict whether the binaural hearing aid fitting will be successful, which can be crucial for patient counseling and clinical decision making.

Dichotic listening is more commonly used as a screening tool or diagnostic test for the evaluation of auditory processing skills (Jerger & Musiek, 2000). Lesion studies (Kimura, 1961a; Musiek, Kibbe, & Baran, 1984) have demonstrated disordered patterns of dichotic recognition performance, in the form of significantly large ear advantages, on dichotic listening tasks for individuals with damage along the auditory pathways. The results of these lesion studies, in conjunction with those studies demonstrating what constitutes normal dichotic listening skills (Dirks, 1964; Noffsinger, Martinez, & Wilson, 1994; Wilson & Jaffe, 1996; Wilson & Leigh, 1996; Strouse & Wilson, 1999; Roup, 2011), allow for extrapolation regarding the dichotic listening abilities of those with auditory processing difficulties but no identifiable lesion. Thus, dichotic listening tasks can be used to differentiate individuals with normal auditory processing skills from those with disordered auditory processing by comparing the relative magnitude of the REA across these populations (Keith & Anderson, 2007). Dichotic listening tasks are currently used to evaluate auditory processing as part of a number of auditory processing test batteries, including the Staggered Spondaic Word (SSW) test (Katz, 1962), the Multiple Auditory Processing Assessment (MAPA) test battery (Domitz & Schow, 2000), and the SCAN-3:A Tests for Auditory Processing Disorders (Keith, 2009).

Research Question and Hypotheses

The SCAN-3:A Tests for Auditory Processing Disorders (Keith, 2009) is an auditory processing test battery for use with adolescents and adults. It is composed of diagnostic and screening tests which evaluate the patient's performance across the following tasks: a filtered words subtest; a dichotic words subtest; a dichotic sentences subtest; an auditory figure-ground subtest; and two screening tests, gap detection and time compressed sentences (Keith, 2009). Anecdotal clinical evidence suggests that the

SCAN-3:A is insensitive to auditory processing complaints in young adults. Specifically, it is argued that the SCAN-3:A subtests are not difficult enough to yield performance consistent with the subjective complaints of young adult patients. This claim is supported by Lovett and Johnson (2010), who indicate that the poor reliability and validity of the SCAN-3:A make it a tool appropriate for screening purposes only, rather than for making clinical diagnoses in the adult population. An additional argument against the use of the SCAN-3:A specific to the dichotic words subtest is the scoring method, which focuses on overall performance rather than examining performance by ear (Keith, 2009). Using a scoring system that ignores individual ear performance effectively washes away any ear advantage that would be indicative of an auditory processing issue. Based on these criticisms of the SCAN-3:A, the present study seeks to answer the following question: Is a dichotic speech recognition task using filtered words more sensitive to auditory processing complaints in young adults than the SCAN-3:A? The rationale for using a filtered dichotic speech recognition task with this group of subjects is as follows. The use of filtering was hypothesized to decrease overall performance on a dichotic speech recognition task from the ceiling effects often seen for normal-hearing young adults (Roup, 2011). When the scores for a speech recognition task are moved toward the middle of the psychometric function (i.e., away from zero or 100 percent), the amount of variability in individual performance on the task increases (Hagerman, 1976). It is hypothesized that the increased task difficulty introduced by the filtering of the speech signal will result in a significant increase in REA for those subjects with auditory processing complaints. In contrast, the increased task difficulty introduced by the filtering will have no effect on the REA for the control group of subjects without auditory processing complaints, as is seen in previous studies (Dirks, 1964; Roup, 2011).

An additional aim of the current study was to collect normative data in the young adult population using a modified version of the Children's Auditory Processing Performance Scale (CHAPPS) (Smoski, 1990). The CHAPPS is a rating scale that evaluates auditory processing abilities across a number of listening situations. Originally created for use with school-aged children, the CHAPPS was used in the present study in order to determine if it is a sensitive screening tool for auditory processing issues in the young adult population.

The purpose of creating this dichotic speech recognition task, as well as modifying the CHAPPS for use with the young adult population, was not to create a diagnostic test or a screening tool that would stand alone. Instead, the goal was to provide a dichotic listening task and auditory processing screening questionnaire that may serve to augment the current auditory processing disorder (APD) test battery and exist as part of the multi-factored, multidisciplinary approach to APD diagnosis and intervention as is recommended in the literature (AAA, 2010, Bellis & Ferre, 1999).

CHAPTER TWO

Literature Review

Auditory Processing Disorder

Definition.

The American Academy of Audiology (AAA) and the American Speech-Language-Hearing Association (ASHA) define an auditory processing disorder as a perceptual issue affecting the way in which the central auditory nervous system (CANS) understands and makes use of auditory information (ASHA, 2005; AAA, 2010). One key aspect of this definition of APD is the presence of auditory processing deficits in the absence of peripheral hearing loss (Moore, 2006; Jerger & Musiek, 2000). Classic auditory processing deficits often attributed to APD include: difficulty hearing in the presence of background noise, difficulty following orally presented instructions, difficulty listening in less than optimal acoustic environments, lack of appreciation for or understanding of music, academic difficulties, and decreased auditory association abilities (Bamiou, Musiek, & Luxon, 2001; Chermak, Somers, & Seikel, 1998; AAA, 2010). Any combination of complaints secondary to these deficits may be seen in the case history of a patient with suspected APD.

Prevalence estimates.

Estimates of the prevalence of APD are often limited to the prevalence of the disorder in children or older adults. It is estimated that two to three percent of school-aged children present with auditory processing difficulties consistent with APD (Chermak & Musiek, 1997). Estimates of the prevalence of APD increase in the older adult population, where auditory processing deficits secondary to the effects of aging are estimated to occur in 10 to 20 percent of the population (Cooper & Gates, 1991). In young adult populations, the incidence of APD has been examined in a subset of individuals with traumatic brain injuries. It was found that in a group of 19 subjects who experienced closed head injuries, 11 subjects demonstrated performance on tests of auditory processing consistent with APD, resulting in a incidence of APD of 58 percent in this group (Bergemalm & Lyxell, 2005). While no research has been conducted in the United States to investigate the prevalence of APD in young adults without clinically identifiable brain insults, Saunders and Haggard (1989) suggested that adults with auditory processing complaints in the absence of hearing loss or neurophysiologic insults comprise five percent of the audiologic patient population in the United Kingdom.

Early APD research.

Early research in APD examined auditory processing deficits in individuals with identifiable brain insults. Bocca, Calearo, and Cassinari (1954) documented patients with temporal lobe tumors who presented with normal hearing thresholds and significant impairments in speech recognition using low-pass filtered speech stimuli. Speaks, Gray, and Miller (1975) demonstrated dichotic listening impairments using consonant-vowel (CV) syllables, also in patients with temporal lobe tumors. In both studies, the results showed that performance was poorer in the ear contralateral to the site of lesion, consistent with the theory that the auditory system is predominantly contralateral in nature (Kimura, 1961a; Kimura, 1961b; Kimura, 1967). Musiek (1983) reported a similar pattern of response on dichotic speech recognition tasks in individuals with hemispheric insults, but indicated that those subjects with brainstem lesions showed a greater deficit in dichotic speech recognition for those stimuli presented ipsilateral to the site of lesion. Musiek, Kibbe, and Baran (1984) found that individuals with a surgically removed corpus callosum demonstrated normal pure tone thresholds, and normal filtered speech recognition, with significant post-operative impairments in dichotic listening for stimuli presented to the left ear, supporting the idea that the corpus callosum plays a significant role in the transfer of auditory information between hemispheres. Taken together, these early studies demonstrate the profile associated with APD today: normal pure tone audiograms associated with significant impairment in tasks of auditory processing. Lesion studies provide a means of establishing the sensitivity and specificity of auditory processing tests by providing a subject group with known lesions affecting auditory processing (Musiek, Bellis, & Chermak, 2005). Understanding the consistent patterns of performance by individuals with known lesions on auditory processing tasks aids in the diagnosis of APD in individuals with similar patterns of performance but no identifiable CANS lesions.

Causes and related disorders.

Many individuals seen for APD evaluations have no apparent lesions, infections, or diseases that could be related to their auditory processing deficits (AAA, 2010). However, in addition to auditory processing deficits secondary to neurophysiologic insults, APD can be attributed to a number of other causes, and is often considered to have a high level of co-morbidity with other behavioral, learning, or language disorders. APD symptoms secondary to the delayed maturation of the auditory system may present in children born prematurely and with a low birth weight, though their auditory processing skills are expected to improve throughout adolescence (Davis et al., 2001). Certain infectious diseases have been suggested to cause APD, including bacterial meningitis (Huggoson et al., 1997) and Lyme disease (Bloom et al., 1998). Lead exposure has also been linked to auditory processing deficits (Dietrich et al., 1992).

Attention deficit hyperactivity disorder (ADHD) has also been linked to APD as a potentially related disorder (Gascon, Johnson, & Burd, 1986; Pillsbury et al., 1995). Riccio et al. (1996) suggested that while both disorders may involve disturbances in auditory attention, they are in fact distinct disorders that do not necessarily co-occur. Riccio et al. (2005) supported this idea by demonstrating the lack of association between measures of auditory processing and measures of attention. Chermak, Somers, and Seikel (1998) and Chermak, Tucker, and Seikel (2002) have also demonstrated the lack of overlap between the reported symptoms of ADHD and APD. Differential diagnosis of these two disorders requires the audiologist to collect case history and diagnostic information specific to the auditory modality (Chermak, 2007), being mindful of the possibility of decreased attention on the patient's part that could incorrectly affect test results (AAA, 2010).

Language disorders can mimic APD, as the inability to understand the speech signal can be attributed to either auditory processing difficulties or language processing difficulties. A language processing disorder occurring in isolation would be demonstrated by an ability to perceive the speech stimuli acoustically but an inability to determine its meaning on a linguistic level (Richard, 2007). Based on the results of the APD evaluation, it may be appropriate for the audiologist to refer the patient for a language evaluation if language deficits are suspected (AAA, 2010). Similarly, learning disabilities, defined as performance deficits not reflective of an individual's intelligence, can confound APD evaluations. Awareness of a patient's learning disability is important in the evaluation of a patient's auditory processing skills and interpretation of test results (Richard, 2007). In light of the various disorders associated with APD, AAA (2010) advocates for a multidisciplinary assessment of APD which serves to rule out confounding variables while also providing a clear picture of the patient's functional deficits across various modalities.

Diagnosis in Adults.

Despite the variety of proposed causes and related disorders attributed to APD, the definition and diagnosis of APD have recently shifted their focus to evaluating the heterogeneous functional deficits of the disorder, rather than determining the etiology (Moore, 2006; Bamiou, Musiek, & Luxon, 2001). Individuals at risk for APD and in need of an APD evaluation can be identified using screening questionnaires which examine the functional impact of APD. Unfortunately, at the present time, screening questionnaires for APD with normative data have only been developed for the pediatric population. One such screening questionnaire is the Children's Auditory Processing Performance Scale (CHAPPS) (Smoski, 1990). The CHAPPS is a widely used screening questionnaire consisting of 36 questions which evaluate the patient's auditory processing abilities across six conditions: in noise, in quiet, in an ideal listening environment, with multiple inputs, regarding the patient's auditory memory and sequencing, and their auditory attention span. Each question asks the respondent, often the patient's parent or teacher, to rate the patient as they compare to their normal-hearing peers with no auditory processing concerns. Deficits revealed on this questionnaire may provide insight into whether or not the patient needs a full APD evaluation, and what tests should be included.

Prior to the completion of the behavioral test battery often used in APD evaluations, an extensive case history including medical, educational, and developmental history as well as speech, language, and social development should be obtained (Jerger & Musiek, 2000; AAA, 2010). AAA (2010) recommended a diagnostic approach to APD including both behavioral and electrophysiologic measures of auditory processing function. The development of the behavioral test battery for APD is based on the comparison of one individual's performance across several auditory processing tasks to what is considered to be typical auditory processing. Typical auditory processing is defined by age-appropriate abilities across the following auditory processes: localization and lateralization, binaural integration and separation, temporal integration and separation, pattern recognition, and understanding speech when presented with competing or degraded signals (ASHA, 2005). Thus, the behavioral auditory processing test battery is composed of a series of tasks which seek to determine if the patient's underlying auditory processing abilities are age-appropriate, or if the auditory processing complaints the patient presents with are consistent with deficits in the test battery results. Possible tests in the behavioral test battery include the masking level difference (MLD), filtered word recognition or monaural low redundancy tasks, temporal processing and patterning tasks such as frequency sequencing and gap detection, discrimination tasks such as frequency and intensity difference limens, and dichotic speech recognition tasks (ASHA, 2005; Baran, 2007).

Dichotic Speech Recognition

Dichotic speech recognition was first presented in the literature by Broadbent (1954), who discussed the task as it related to the listening difficulties faced by air traffic control personnel. Following Broadbent (1954), other early research (Dirks, 1964; Kimura, 1961a; Kimura, 1961b; Kimura, 1967) examined patterns of performance in normal-hearing listeners and listeners with neurophysiologic lesions. These early studies helped to determine what would be considered normal performance on a dichotic listening task, and served to aid researchers in theorizing the neurophysiologic basis for the patterns of response seen on this type of speech recognition task.

Dichotic speech recognition tasks, as previously mentioned, involve the simultaneous presentation of different speech stimuli to both ears, requiring the listener to repeat one or both of the stimuli heard (Keith & Anderson, 2007). The REA, or more stimuli reported from the right ear compared to the number of stimuli reported from the left ear, is often found in normal-hearing young adults (Dirks, 1964; Kimura, 1967; Wilson & Jaffe, 1996; Wilson & Leigh, 1996; Strouse & Wilson, 1999; Roup, 2011). The REA is thought to reflect the functional asymmetry of the auditory system and the strength of its contralateral pathways (Kimura, 1961a; Kimura, 1961b; Dirks, 1964; Kimura, 1967). This is known as the structural theory. The structural theory is based on the fact that the auditory pathway has larger and more numerous connections from each ear to the contralateral hemisphere than those connections found in either ipsilateral pathway. Thus, information presented to the right ear reaches the left hemisphere for processing more efficiently, resulting in the REA (Kimura, 1961a; Kimura, 1961b; Kimura, 1967; Bryden, 1988).

In addition to the structural theory reported by Kimura (1961a; 1961b; 1967), an attentional theory was proposed by Kinsbourne (1970). The attentional theory supposes that the ear advantage seen in dichotic tasks is the result of an attentional bias to one ear over the other, dependent upon the type of stimuli used. While Kinsbourne (1970) did acknowledge the existence of a structural asymmetry in the neural pathways, he argued that the asymmetry in dichotic listening performance is a biological process that is determined by the type of stimulus that is presented (i.e., verbal versus non-verbal). He provided evidence to support his theory using a visual gap detection task. For the first part of the task, subjects were only required to indicate if a gap was present in a visually presented square stimulus. In the second part of the task, subjects were given six key words and asked to repeat the first three words if the gap occurred on the left side of the square, and the last three words if the gap was seen on the right side. The results showed that the introduction of verbal material resulted in an asymmetry in performance where gaps on the right side were reported more accurately than gaps on the left side. Kinsbourne (1970) concluded that these results were in support of the attentional model, as the introduction of verbal material resulted in an advantage for the left hemisphere that did not exist when the stimuli were purely visual.

Stimulus effects.

Overall performance, and the magnitude of the ear advantage seen in dichotic listening tasks, are dependent upon the type of stimuli used (Bryden, 1988). Wilson and Jaffe (1996) used 1-, 2-, 3-, and 4-digit sequences to examine the effects of task difficulty in normal-hearing young adults and hearing-impaired older adults. They found that as the length of the digit sequence increased, performance decreased across both subject groups.

Wilson and Jaffe (1996) also reported that while right ear performance stayed fairly consistent regardless of the length of the digit sequence, left ear performance declined consistently as the difficulty of the task increased, resulting in an increased REA as a function of task difficulty. Using the VA-CD dichotic sentences, dichotic digits, and dichotic consonant-vowel-consonant (CVC) stimuli, Noffsinger, Martinez, and Wilson (1994) found that normal-hearing young adults achieved performance close to 100 percent on 1-pair dichotic digits and dichotic sentences tasks, with lower performance and greater variability on dichotic CVC tasks. No significant ear advantage was reported for any task among the young adult subjects. Similarly, Noffsinger, Martinez, and Andrews (1996) examined the same tasks using older adult subjects, and found that performance was highest for the 1-pair dichotic digits task, with a slight decrease in performance on the dichotic sentences task, and a dramatic decrease in performance on the dichotic CVC task. As performance declined across these three tasks, the magnitude of the REA increased. Taken together, these studies indicate that an individual's overall performance is a function of task difficulty, resulting in stimulus-dependent variability in what is considered normal performance on dichotic listening tasks. These studies also demonstrate the difference in ear advantage seen between young adult and older adult subjects, often attributed to the auditory processing difficulties associated with the older adult population (Roup, 2011), to be discussed in the following section.

Right ear advantage.

A relatively small REA is considered consistent with normal performance on dichotic tasks for normal-hearing young adults, regardless of task difficulty (Dirks, 1964; Noffsinger, Martinez, & Wilson, 1994). Roup (2011) found that the introduction of noise used to simulate peripheral hearing loss during a dichotic speech recognition task served to decrease overall performance as compared to performance on a quiet dichotic speech recognition task in normal-hearing young adults. However, the REA was not significantly different across these two tasks. In contrast, when compared to previously published data (Roup, Wiley, & Wilson 2006), older adults were found to have overall performance on the quiet dichotic speech recognition task similar to that of the young adults' performance on the same dichotic speech recognition task in noise, but with a significantly larger REA. These findings were attributed to auditory processing issues in the older adult population, rather than task difficulty or peripheral hearing loss. The results of Roup (2011) support the idea that dichotic speech recognition tasks are able to differentiate individuals with normal auditory processing skills from those with disordered auditory processing by comparing the relative magnitude of the REA across these populations (Keith & Anderson, 2007).

Directed attention conditions.

The use of directed attention paradigms in dichotic speech recognition tasks can also serve to differentiate true auditory processing deficits from other issues that may confound results, such as cognitive dysfunction (Jerger, 1997; Carter, Noe, & Wilson, 2001). Directed attention conditions require the listener to either repeat stimuli from the directed ear only, or to repeat words from the directed ear first, then repeat those words heard from the non-directed ear. Directed attention conditions have been found to decrease variability in dichotic listening tasks and increase performance for the directed ear, as subjects are provided with a listening strategy not afforded in the free recall condition (Bryden, Munhall, & Allard, 1983; Asbjornsen & Hugdahl, 1995). Jerger

(1997) indicated that performance on dichotic listening tasks was dependent upon the cognitive demands of the task and the auditory pathway of the individual. Jerger (1997) also described four patterns of performance, using free recall and directed attention paradigms, which could be used to interpret dichotic listening performance and determine if performance was normal, the result of cognitive dysfunction, or the result of true auditory processing dysfunction. The first pattern, normal performance under all response conditions, is indicative of normal auditory function. The second pattern, abnormal performance for the free recall condition with normal performance for the directed attention conditions, is considered indicative of a cognitive issue, as the directed attention condition is considered to reduce the demands of attention and memory, resulting in improved performance for those individuals with cognitive dysfunction. The third pattern, abnormal performance for directed attention conditions with normal performance for the free recall condition, is considered reflective of auditory processing deficits. Finally, the fourth pattern, abnormal performance under all response conditions, is also considered to be consistent with auditory processing deficits. Therefore, the use of directed attention paradigms in conjunction with the free recall response condition can serve to decrease the variability found in the free recall condition, as well as helping to differentiate between normal auditory processing, auditory processing deficits, and cognitive dysfunction.

Handedness.

Handedness is another source of variability in dichotic listening tasks. Kimura (1961b) indicated that for individuals found to process speech in the right hemisphere, a left ear advantage (LEA) was consistently elicited. Kimura (1961b) also noted that for individuals who processed speech in the left hemisphere, a REA was found. Kimura (1961b) indicated that cerebral dominance for speech processing was not necessarily consistent with handedness, as those subjects for whom the right hemisphere was responsible for speech processing were not always left-handed, and vice versa. Wilson and Leigh (1996) supported these findings, indicating a consistent, strong REA for right-handed individuals, with a smaller, more variable REA found in left-handed individuals. These results are consistent with the idea that while many left-handed individuals exhibit a REA and thus are likely to process speech in the left hemisphere, a great amount of variability exists in the left-handed population when compared to the right-handed population. The reduced variability in dichotic listening performance found in the right-handed population is the reason why most studies examining dichotic speech recognition use right-handed subjects only.

Clinically used dichotic speech recognition tasks.

Clinically, several dichotic listening tasks with normative data are used to evaluate auditory processing skills in children and adults. Included among these is the Staggered Spondaic Words (SSW) task (Katz, 1962), one of the first clinically available dichotic speech recognition tasks, which uses the dichotic presentation of two spondee words, in which the second syllable of the first word overlaps with the first syllable of the second presented word. Additional tasks include the previously mentioned VA-CD dichotic sentences, adapted from the Dichotic Sentence Identification Test (DSI) (Fifer et al., 1983), as well as the VA-CD dichotic digits and dichotic CVC tasks, all of which have normative data in the normal-hearing young adult and hearing-impaired older adult populations (Noffsinger, Martinez, & Wilson, 1994; Noffsinger, Martinez, & Andrews, 1996; Wilson & Jaffe, 1996; Wilson & Leigh, 1996). The Multiple Auditory Processing Assessment (MAPA) (Domitz & Schow, 2000) includes a dichotic digits task and a competing sentences task, similar to the SCAN-3:A Tests for Auditory Processing Disorders (Keith, 2009), which uses a competing sentences task and a dichotic words task as part of its test battery for evaluating auditory processing performance.

Filtered Speech Recognition

Monaural low-redundancy speech tasks, or filtered words tests (Krishnamurti, 2007), represent another task from the APD test battery included in the SCAN-3:A (Keith, 2009) considered significant to the present study. As previously discussed, Bocca, Calearo, and Cassinari (1954) used low-pass filtered phonetically balanced words to assess the speech recognition abilities of patients with temporal lobe tumors. It was found that the speech recognition score for the ear opposite the site of lesion was much poorer than the score for the ipsilateral ear using a filtered speech recognition task. This difference in performance across ears was not found using pure-tone audiometry or an unfiltered speech recognition task. Filtered speech recognition tasks serve the purpose of decreasing the extrinsic redundancy of the speech signal. If there is a breakdown in the intrinsic redundancy of the CANS (i.e., a lesion), then the listener will have significantly poorer scores on a filtered speech recognition task than on an unfiltered speech recognition task, as the listener's disordered CANS would be unable to compensate for the missing information in the degraded speech signal. In contrast, a listener with an intact CANS should have similar performance across the unfiltered and filtered tasks, as their CANS is able to process both speech signals with relative ease (Krishnamurti, 2007). Thus, the filtered words task is able to differentiate individuals with disorders of the CANS from the normal population.

SCAN-3:A Tests for Auditory Processing Disorders in Adolescents and Adults

As previously noted, the SCAN-3:A Tests for Auditory Processing Disorders (Keith, 2009) is a test of auditory processing in young adults. The SCAN test battery is an established test battery for auditory processing disorders which is widely used among audiologists who screen for and diagnose APD (Emanuel, Ficca, & Korczak, 2011). The SCAN test battery has existed in several iterations, based originally on the SCAN-A Screening Test for Auditory Processing Disorders (Keith, 1986). The SCAN-3:A includes the following diagnostic tests: a filtered words task which evaluates the patient's ability to recognize speech from a distorted signal; a dichotic words task which evaluates the patient's binaural integration abilities; a dichotic sentences task which evaluates the patients binaural separation abilities; an auditory figure ground task which evaluates the patient's ability to understand speech in the presence of background noise; and two measures of temporal processing, gap detection and time compressed sentences (Keith, 2009).

Lack of sensitivity of the SCAN-3:A.

While the SCAN-3:A is widely used in audiologic clinics providing auditory processing evaluations, it is not without flaws. In the test manual included with the SCAN-3:A, Keith (2009) described a study using the SCAN-3:A which compared performance between two subject groups: 61 individuals, ages 13 to 50 years, who were previously diagnosed with APD, and an age-matched control group of 61 individuals with no auditory processing concerns. A significant difference in performance between the groups was seen on each subtest except the filtered words subtest, as well as for composite scores. Keith (2009) concluded that these results reflected the ability of the SCAN-3:A to differentiate between individuals with normal auditory processing and individuals with APD. However, when examining the mean performance between each group in the study Keith (2009) detailed, it is evident that for the subject group consisting of individuals previously diagnosed with APD, average performance across each subtest of the SCAN-3:A is within the normal range according to the scaled score cut-offs provided in the test manual. This indicates that while the SCAN-3:A may have the potential to differentiate between individuals with normal auditory processing skills and those individuals with APD, the scoring system inherent to the test itself may incorrectly categorize individuals with true auditory processing deficits as performing within the normal range. Though this claim is based on the mean scores provided by Keith (2009), and not individual performance, it can be assumed based on the relatively high mean scores that some of those subjects in the APD subject group performed in the normal range according to the standardized scoring of the test battery. These results support the claim of the present study that the SCAN-3:A is not a sensitive measure of subtle auditory processing deficits in young adults. Though the SCAN-3:A is able to differentiate between normal and abnormal auditory processing, data included in the test booklet suggest a lack of sensitivity for at least some normal-hearing young adults with APD.

Goals of the Present Study

There were two goals of the present study. The first was to determine whether a filtered dichotic word recognition task was a sensitive measure of subtle auditory processing complaints in normal-hearing young adults. The second goal was to collect data to determine if a revised version of the CHAPPS (Smoski, 1990) was sensitive to auditory processing complaints in normal-hearing young adults. It was hypothesized that a significant difference in overall performance and ear advantage scores on the filtered dichotic word recognition task would be found between a group of individuals with auditory processing complaints but with normal to borderline performance on the SCAN-3:A, and a group of individuals with no auditory processing complaints and normal performance on the SCAN-3:A. It was suggested that these results would support the theory that a filtered dichotic word recognition task is more sensitive to subtle auditory processing deficits in young adults than the SCAN-3:A. Finally, it was hypothesized that a comparison of scores from the revised CHAPPS (Smoski, 1990) would reveal significant differences in performance across the two subject groups, indicating that the CHAPPS may be appropriate for use in young adult populations.

CHAPTER THREE

Methods

Subjects

Subjects in the present study were twenty-four young adults ranging in age from 19 to 38 years (mean = 23.5 years). All subjects had normal hearing sensitivity as defined by pure tone thresholds ≤ 20 dB HL from 250 to 8000 Hz, and bone conduction thresholds within 10 dB of air conduction thresholds from 500 to 4000 Hz. Inclusion criteria for the present study were as follows: 1) normal otoscopy; 2) a negative history of significant ear pathology; 3) screening tympanometry within normal limits (Roup, Wiley, Safady, & Stoppenbach, 1998); 4) native speaker of English; and 5) a laterality quotient ≤ 40 consistent with right-handedness according the Edinburgh Handedness Inventory (Oldfield, 1971); and 6) no obvious cognitive deficit or diagnosed developmental disorder.[1] Case history information was collected for each subject prior to participation in the present study. Each subject was asked questions from a revised version of the CHAPPS (Smoski, 1990) to determine their auditory processing complaints, or lack thereof for the control group. An additional component of the case history collected from each subject was a set five of screening questions that were used to determine into which subject group each subject should be placed. These questions were created based on the list of behaviors commonly associated with APD provided by AAA (2010). The

[1]One subject had scores on the Edinburgh Handedness Inventory (Oldfield, 1971) consistent with left-handedness; however, he was included in the present study because his performance on the dichotic speech recognition tasks was consistent with that of the right-handed subjects. His inclusion was also based on his normal performance on the SCAN-3:A despite his extensive case history involving traumatic brain injury and handicapping auditory processing deficits. Despite the traumatic brain injury, this subject appeared to function without any obvious cognitive deficits.

functional deficits addressed by the these questions include difficulties with localization of sound, difficulties understanding speech in the presence of background noise, difficulties ignoring environmental sounds, and an inability to understand verbally presented directions and messages (see Appendix A). Each question was placed on a 7-point Likert scale, with answers ranging from ‘never’ to ‘always’. A point value was assessed to each possible answer in a linear manner, such that a response of ‘never’ was equal to a score of 0, and a response of ‘always’ was equal to a score of 6. Answers to these questions, in conjunction with scores of the SCAN-3:A, determined in which group each subject was placed. Subjects in the normal control group received a total score between 0 and 10 on these five screening questions. Subjects in the probable and diagnosed APD groups received a total score between 11 and 30. An additional inclusion criterion for the APD subject groups was a response of ‘almost always’ or ‘always’ on any single screening question, indicating significant deficits in one area. This two-fold scoring system was sensitive to both individuals with global auditory processing issues, and those individuals with significant issues in one area only. The rationale for using this system is based on the AAA Clinical Practice Guidelines for APD (AAA, 2010), which indicate that while the report of significant functional difficulties in auditory processing is not sufficient for a diagnosis of APD, individuals who indicate significant difficulties across one or more of the above-mentioned functional areas should be considered at-risk for APD, and thus an evaluation of auditory processing skills would be appropriate.

In addition to total scores from the five screening questions, subjects were split into two groups based on their performance on the SCAN-3:A. Ten subjects with no history of auditory processing complaints, as indicated by a score of 0 to 10 on the screening questions outlined above, and normal results on the SCAN-3:A were placed in the normal control group. Fourteen subjects reported a history of auditory processing complaints, consistent with a score of 11 to 30 on the screening questions, but denied a formal diagnosis of auditory processing disorder and had SCAN-3:A results in the normal to borderline range. These subjects were placed in the probable APD group. Subjects were recruited from the Ohio State University student population as well as from the Ohio State University Speech-Language-Hearing Clinic, both in Columbus, Ohio. All subjects were compensated for their time.

Materials

As a part of the subject's case history information, a revised version of the CHAPPS (Smoski, 1990) was used to assess the subject's auditory processing abilities in several listening situations: quiet, listening in noise, ideal listening environments, multiple inputs, auditory memory, and auditory attention. Though this checklist was designed for use with school-aged children, it was revised for use in the present study in order to determine if it was sensitive to auditory processing difficulties in young adults. The revision was done in order to make the questionnaire more age-appropriate for the subjects in the present study. This was completed by removing all references to children and activities associated with children, such as coloring. The directions were also revised, as the original CHAPPS was meant for parents or teachers to answer, rather than the children themselves. Thus, the directions were changed in such a way that the questionnaire became a self-report, rather than observational, questionnaire. Despite these changes, the revised CHAPPS remains a faithful representation of the original CHAPPS in terms of content and scoring (see Appendix B).

The diagnostic tests from the SCAN-3:A (Auditory Figure Ground, Filtered Words, Competing Words, and Competing Sentences) were administered to all subjects in order to establish auditory processing abilities according to this specific test battery. Additionally, each subject was administered a filtered dichotic words task and an unfiltered dichotic words task using monosyllabic words from the same set of stimuli. The stimuli for the experimental dichotic words tasks were adapted from Findlen and Roup (2011) (see Appendix C). The original words were taken from stimulus lists created by Boothroyd and Nittrouer (1988), and were re-recorded by a male speaker (Findlen & Roup, 2011). The purpose of using these stimuli was to allow for consistency across experimental tasks in terms of the type of voice used, as the subtests of the SCAN-3:A use a male speaker. Stimuli were paired based on their neighborhood density rating according to the Neighborhood Activation Model (Luce & Pisoni, 1998), such that words within a given dichotic pair had similar recognition difficulty. Each word list consisted of novel dichotic pairings to eliminate any repetition of word pairs, and stimuli were counterbalanced across channels so that each stimuli was presented at least one time per ear per subject. The interstimulus interval (ISI) between dichotic word pairs was 5 seconds. All stimuli for the filtered dichotic words task were filtered using a digital eighth-order Butterworth filter (48 dB/octave), with a center frequency of 1500 Hz, a high-pass cut off of 892 Hz and a low-pass cut off of 2521 Hz. This resulted in a filtered bandwidth of 1.5 octaves. A total of 150 pairs of words were used in the present study, resulting in 6 different lists consisting of 25 pairs each. Of these six lists, three were presented in the unfiltered condition, and three were presented in the filtered condition. The lists were pseudo-randomized across subjects prior to presentation.

Procedures

Both the filtered and unfiltered dichotic words experimental tasks were presented to all subjects. Within each of these dichotic words tasks, three lists of 25 dichotic words pairs were presented. Each list represented a different response condition: free recall, directed right, and directed left. The free recall response condition required the subject to repeat both of the presented words in any order. This response condition was always presented first as it is not thought to provide the subject with a listening strategy. The directed right and directed left response conditions required the subject to focus their attention on the directed ear and to repeat the corresponding word first, followed by the word presented to the opposite ear. Practice trials of each dichotic stimulus were presented to each subject prior to the corresponding experimental condition. The order of presentation of the directed attention tasks was pseudo-randomized across subjects to avoid any order effects.

All experimental materials were directed from a CD player (Sony CE375) through a two-channel audiometer (Grason Stadler, Model 61), and presented at 50 dB HL using ER-3 insert earphones. The presentation level was chosen as it is the recommended presentation level for the SCAN-3:A test materials (Keith, 2009). Each subject completed a single 1.5 hour experimental session. All audiometric and experimental testing was completed in a double-walled sound-attenuating booth (IAC 403 ATR). All equipment used (audiometer, tympanometer) was calibrated according the appropriate American National Standards Institute standards (ANSI, 1987, 2004).

CHAPTER FOUR

Results

Mean dichotic word recognition performance and standard deviations for the unfiltered and filtered conditions are presented in Table 1. For both the normal control and probable APD groups, there was a general trend of dichotic word recognition performance, in which scores in the unfiltered condition were better than scores in the filtered condition. For example, the normal control group demonstrated mean performance of 92.4% correct word recognition in the unfiltered free recall condition for the right ear, compared to a mean of 53.2% correct word recognition in the right ear for the filtered free recall condition. The probable APD group demonstrated a similar shift in mean performance despite performing more poorly than the normal control group, with a mean of 85.4% correct word recognition for the right ear in the unfiltered free recall condition, and a mean of 47.4% correct for the right ear in the filtered free recall condition. Variability in performance was found to increase in the filtered condition for the normal control group, as demonstrated by larger standard deviations (SD) in the filtered condition as compared to the unfiltered condition. The largest SD for the normal control group in the unfiltered condition was 10.3 for the ear advantage found in the directed right condition. In the filtered condition, the largest SD was 18.3, for the ear advantage found in the free recall condition. A greater amount of variability in performance was demonstrated by the probable APD group in both the unfiltered and

TABLE 1. Mean dichotic word recognition performance (in percent correct) and standard deviations (SD) for the normal control group and probable APD group for the two experimental conditions: unfiltered and filtered.

	Right Ear (%)	Left Ear (%)	RE – LE (%)
Normal Control Group (n=10)			
Unfiltered			
Free Recall	92.4 (4.0)	86.4 (5.1)	6.0 (6.6)
Directed Right	93.6 (5.7)	82.8 (13.3)	10.8 (10.3)
Directed Left	91.2 (4.5)	91.2 (3.2)	0.0 (6.0)
Filtered			
Free Recall	53.2 (14.7)	48.4 (12.9)	4.8 (18.3)
Directed Right	66.4 (9.5)	49.6 (13.0)	16.1 (14.6)
Directed Left	51.2 (9.4)	54.1 (13.1)	-2.8 (11.6)
Probable APD Group (n=14)			
Unfiltered			
Free Recall	85.4 (11.7)	74.6 (17.2)	10.9 (13.0)
Directed Right	91.1 (7.2)	77.7 (15.2)	13.4 (11.2)
Directed Left	86.9 (11.9)	77.1 (12.1)	9.7 (13.3)
Filtered			
Free Recall	47.4 (18.2)	39.7 (19.8)	7.7 (17.9)
Directed Right	55.1 (19.2)	34.6 (15.4)	20.6 (13.7)
Directed Left	47.7 (18.2)	48.0 (15.9)	-0.3 (11.9)

filtered conditions. As seen in Table 1, SDs were greater than 10 in nearly every condition for the probable APD group, with the exception of the SDs for both the right ear performance (SD = 7.2) and ear advantage (SD = 9.7) in the unfiltered directed right condition. This observation is notable, as it underscores the large variability in overall performance found in the probable APD group.

Prior to statistical analysis, percentage data were transformed into rationalized arcsine units (Studebaker, 1985) in order to normalize the error generally associated with using percentage data. In order to determine if overall dichotic recognition performance differed significantly between the normal control and probable APD groups, a 3-way repeated measures analysis of variance (ANOVA) (2 group x 3 response condition x 2 filtering condition x 2 ear) was performed *group* as the between subjects variable, and *filtering condition*, *response condition*, and *ear* as within-subject variables. No significant main effect of *group* was found ($F_{1,22} = 3.923$; $p>.05$), indicating that overall performance between the normal control and probable APD groups was not significantly different. The ANOVA revealed a significant main effect of filtering ($F_{1,22} = 404.774$; $p<.05$), indicating that subjects performed significantly poorer in the filtered condition as compared to the unfiltered condition. The ANOVA also revealed a significant main effect of response condition ($F_{2,44} = 3.829$; $p<.05$), indicating that performance differed significantly across the three response conditions. Post-hoc paired samples t-tests indicated that the normal control group performed significantly better in the filtered directed right response condition as compared to the filtered free recall response condition ($t_{19} = -2.327$, $p<.05$). Additionally, a main effect of ear was found ($F_{1,22} = 40.281$; $p<.05$), indicating that right ear performance was significantly better than left ear performance across subjects. Significant interactions were also noted by the ANOVA. A significant interaction between filtering and ear was found ($F_{1,22} = 6.848$; $p<.05$), reflecting the significantly larger ear advantages seen in the filtered condition as compared to the unfiltered condition for all subjects. A significant interaction between response condition and ear was also found ($F_{2,44} = 15.156$; $p<.05$), indicating a significant difference in ear advantage across the three conditions. This finding reflects the REA seen in the free recall and directed right conditions, and the LEA seen in the directed left condition.

Results were also examined for the dichotic *ear advantage*, the difference score between the right and left ears. A 2-way repeated measures ANOVA (2 group x 3 response condition x 2 filtering condition) was performed *group* as the between subjects variable, and *filtering condition*, *response condition*, and *ear* as within-subject variables to determine whether significant differences in mean *ear advantage* were present across the normal control and probable APD groups. The ANOVA did not indicate a significant difference in performance across the two subject groups ($F_{1,22} = 2.762$; $p>.05$). Figures 1 and 2 present boxplots of ear advantages across response conditions and filtering conditions for the normal control and probable APD groups, respectively. Each boxplot includes the median (thin black line), mean (thick black line), 25th and 75th percentiles (lower and upper box), 10th and 90th percentiles (whiskers), and outliers (dots) defined as all data outside the 10th and 90th percentiles. Positive ear advantages (above the line at zero) indicate a REA, and negative ear advantages (below the line at zero) indicate a LEA. As seen in Figures 1 and 2, the majority of subjects demonstrated REAs across

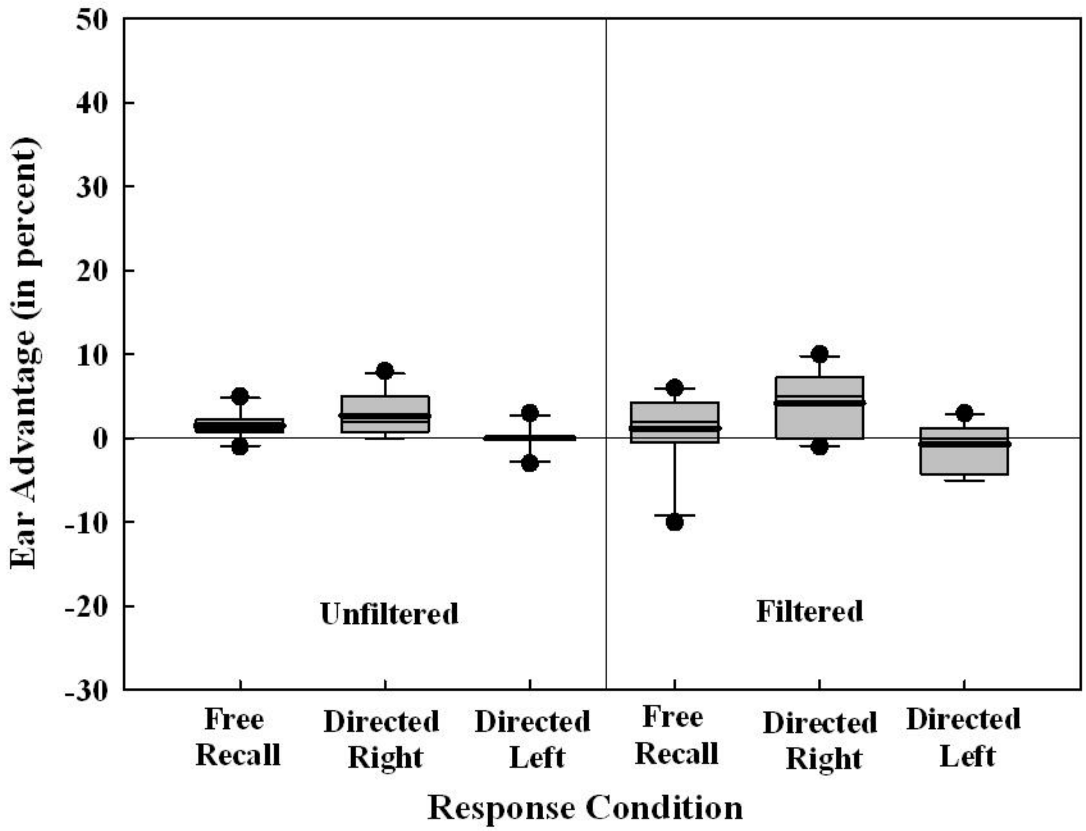

FIGURE 1. Boxplot of ear advantages (in percent) for the normal control group across response conditions: free recall, directed right and directed left response conditions, and filtering conditions: unfiltered and filtered. Each boxplot includes the: median (thin black line), mean (thick black line), 25th and 75th percentiles (lower and upper box), 10th and 90th percentiles (whiskers), and outliers (dots).

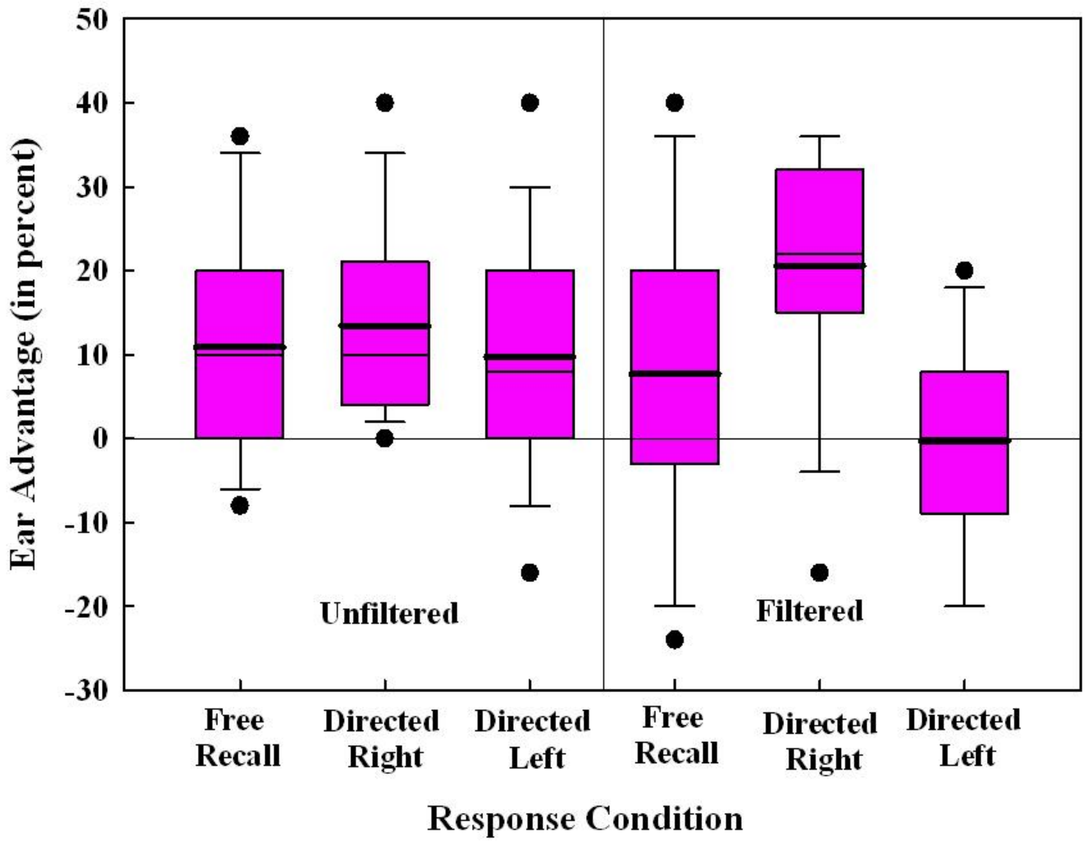

FIGURE 2. Boxplot of ear advantages (in percent) for the probable APD group across response conditions: free recall, directed right and directed left response conditions, and filtering conditions: unfiltered and filtered. Each boxplot includes the: median (thin black line), mean (thick black line), 25th and 75th percentiles (lower and upper box), 10th and 90th percentiles (whiskers), and outliers (dots).

response and filtering conditions. Also evident in Figures 1 and 2 is a large range of performance, particularly for the probable APD group. The lack of significant difference found by the repeated measures ANOVA is likely due to the large variability in ear advantage found within each group and across response and filtering conditions.

A significant main effect of response condition was revealed by the ANOVA of ear advantage ($F_{2,44} = 2166.44$; $p<.05$). Post-hoc paired samples t-tests revealed a significant difference in ear advantage between the unfiltered directed right and unfiltered directed left conditions ($t_{23} = 2.76$, $p<.05$), between the filtered free recall and filtered directed right conditions ($t_{23} = -2.81$, $p<.05$), and between the filtered directed right and filtered directed left conditions ($t_{23} = 6.333$, $p<.05$). In each case, the ear advantage was largest in the directed right response condition.

Given the lack of a significant difference in performance found across the normal control and probable APD subject groups, these groups were reformed using stricter subject criteria. Candidacy criteria for the normal control group (n=10) remained unchanged. The probable APD group was subdivided into two groups based on their SCAN-3:A performance. The APD I group (n=8) was defined as those individuals with auditory processing complaints but normal performance on the SCAN-3:A. The APD II group (n=6) was composed of subjects with auditory processing complaints and borderline scores on at least one subtest of the SCAN-3:A. A second 3-way repeated measures ANOVA (3 group x 3 response condition x 2 filtering condition x 2 ear) was performed *group* as the between subjects variable, and *filtering condition*, *response condition*, and *ear* as within-subject variables, in order to determine whether a difference in performance was found across these three subject groups. The results of this repeated measures ANOVA revealed a significant main effect of group ($F_{2,21} = 4.416$; $p<.05$). A post-hoc Tukey Honestly Significant Difference (HSD) test was performed to determine which of the three groups varied significantly in their dichotic word recognition performance. The results revealed a significant difference in performance between the normal control group and the APD II group ($p<.05$). No significant difference in performance was revealed between the normal control group and the APD I group ($p>.05$), or between the APD I and APD II groups ($p>.05$). These findings indicated that overall performance on these dichotic listening tasks was significantly better for the normal control group than for the APD II group.

Individual performance for each of the three subject groups is presented as bivariate plots in Figure 3. Percent correct recognition for words presented to the right ear are plotted along the abscissa, and percent correct recognition for words presented to the left ear are plotted along the ordinate. The diagonal line across each individual plot indicates equivalent performance for the right and left ear. Data points below this line indicate better recognition of words presented to the right ear, or a REA. Data points above this line indicate better recognition of words presented to the left ear, or a LEA. In the unfiltered condition, represented by Panel A, the control group (circles) performed at ceiling , with little variability. The APD I group (triangles) also showed performance near the ceiling, but with more variability. The APD II group (squares) showed the most variability, as well as the poorest performance. Again, REAs were found for the majority of subjects, while some LEAs were seen in the free recall and directed left response

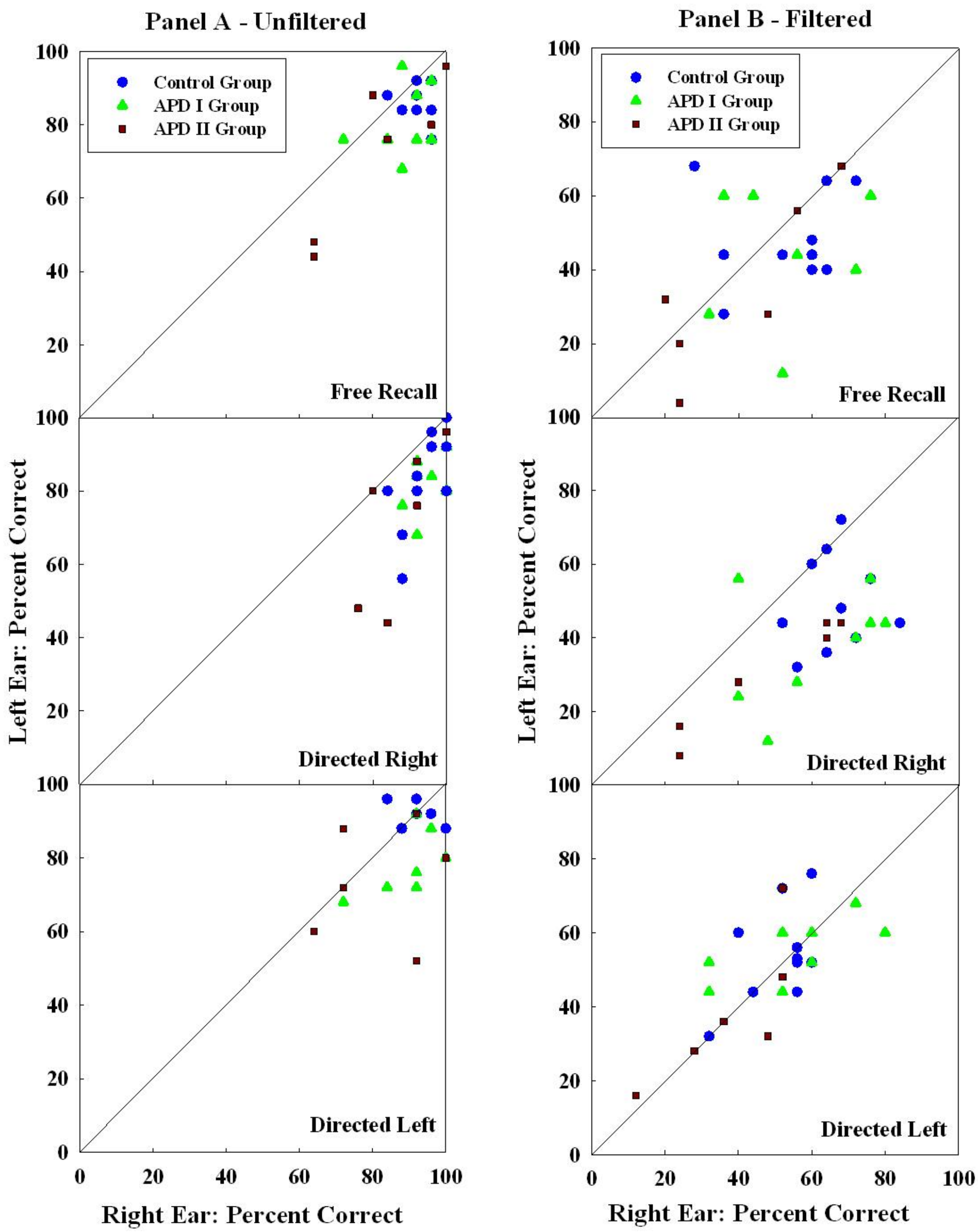

FIGURE 3. Bivariate plots of percent correct recognition for the right ear (abscissa) and percent correct recognition for the left ear (ordinate) across the free recall, directed right, and directed left response conditions, for the unfiltered condition (Panel A) and filtered condition (Panel B)

conditions. When examining the filtered condition performance seen in Panel B, it is evident that overall performance decreased and variability increased for all three subject groups. Additionally, a greater number of subjects exhibited LEAs in the filtered condition, emphasizing the increase in variability in performance as a consequence of the greater task difficulty introduced by the filtering.

An additional purpose of the present study was to determine if results on the CHAPPS (Smoski, 1990) was significantly different between young adults with no auditory processing complaints and young adults with auditory processing complaints. For this statistical analysis, subjects in the APD I and APD II groups were re-combined, as subjects in both groups presented with auditory processing complaints. Mean CHAPPS scores and SDs for the normal control group and the group of subjects with APD complaints are presented in Table 2. The scoring rubric of the CHAPPS asks respondents to compare themselves to their peers in terms of performance in different listening situations. For each question respondents must give a numeric answer between +1 and -5, with +1 indicating less difficulty than their peers in a given listening situation, and -5 indicating an inability to function at all in a given listening situation (see Appendix B). For each subject, an overall score was calculated by summing the numeric scores provided for each of the 36 questions. Overall scores near 0 or positive overall scores on the CHAPPS indicate average or better than average subjective performance across all listening situations. Negative overall scores on the CHAPPS correspond to varying degrees of difficulty across the listening situations. The average CHAPPS score for the probable APD group (-46.6) was more negative than that of the normal control group

TABLE 2. Mean performance and standard deviation for CHAPPS scores for normal control and probable APD groups.

	Mean CHAPPS Score	Standard Deviation
Normal Control Group	-2.8	15.1
Probable APD Group	-46.6	31.9

(-2.8), reflecting the greater prevalence of auditory processing concerns reported by subjects in the probable APD group. A one-way ANOVA (2 group x 1 CHAPPS score) performed with *group* as the between-subjects variable and *CHAPPS score* as the within-subjects variable, revealed that this difference in CHAPPS scores between the two groups was statistically significant ($F_{1,22} = 16.069$; $p<.05$).

CHAPTER FIVE

Discussion

The purpose of the present study was to determine whether a filtered dichotic listening task was sensitive to the auditory processing complaints of normal-hearing young adults. The results of this study revealed no significant difference in performance between a normal control group and a group of normal-hearing young adults with auditory processing complaints and normal to borderline scores on the SCAN-3:A. There are a few possible explanations as to why no significant difference was found. It is possible that the young adults with auditory processing complaints in the present study have normal auditory processing. If this is the case, it would make sense that they would perform within normal limits on the SCAN-3:A, and perform comparably with the normal control group on the filtered dichotic listening task. However, another possibility for this lack of a significant difference in performance is that the filtered dichotic listening task may not be a sensitive measure of the complaints reported by the subjects in the present study. It is possible that the use of dichotic listening and filtered words alone is not sufficient to reflect the auditory processing issues of these subjects. Typically, auditory processing test batteries measuring performance across a variety of behavioral tasks are used to evaluate auditory processing and diagnose auditory processing disorders (ASHA, 2005; Baran, 2007). These test batteries can include temporal processing tasks, frequency sequencing and gap detection, frequency and intensity discrimination tasks, and other speech recognition tasks such as word recognition in background noise (ASHA, 2005). It is possible that the use of a filtered dichotic listening task in conjunction with one or more of these additional auditory processing tasks may provide a better picture of a subject's overall auditory processing abilities, resulting in better sensitivity to the auditory processing complaints reported by the subjects in the present study.

Based on the lack of a significant difference between the normal control and probable APD groups, subject groups were reformed to determine if subjects with borderline performance on the SCAN-3:A and auditory processing complaints (APD II group) performed significantly different on the filtered dichotic listening task when compared to two groups of subjects with normal performance on the SCAN-3:A: one group with auditory processing complaints (APD I group), and one group without auditory processing complaints (normal control group). The results of this second analysis revealed that subjects with borderline performance on the SCAN-3:A performed significantly poorer than the normal control group. These results reflect the findings reported by Keith (2009) in the test manual included with the SCAN-3:A. Keith (2009) compared SCAN-3:A performance between a group of subjects without auditory processing complaints and a group of subjects previously diagnosed with APD. He reported that there was a statistically significant difference in performance between these two groups; however, mean performance for the group of individuals previously diagnosed with APD was still within normal limits according to the scoring rubric of the SCAN-3:A. The results of the Keith (2009) study represent the central argument of the present study: that the SCAN-3:A is not sensitive to auditory processing issues in young adults. It appears based on the results of Keith (2009) and the results of the present study that the scoring mechanism of the SCAN-3:A may be contributing to this lack of sensitivity. Indeed, in both studies, performance on the SCAN-3:A differed between a group of individuals with auditory processing complaints and a control group. However, in both studies, those subjects considered to have auditory processing issues still scored predominantly in the normal to borderline range. It is possible that more normative data is needed for the SCAN-3:A in order to determine what constitutes normal and abnormal performance for this age group. A reworking of normative data and scoring of the SCAN-3:A may help to paint a clearer picture for clinicians as to which patients truly have auditory processing abilities that differ from those of the normal population.

Performance by the subjects in the present study on the filtered dichotic word recognition task was comparable to the performance of the young adults in the Dirks (1964) study. Dirks (1964) reported mean scores of 40.3% and 33.3% for the right and left ears respectively when using filtered phonetically balanced words in a free recall response condition. In the present study, mean scores of 53.2% and 48.4% were found in the filtered free recall response condition for the normal control group. Similarly, the probable APD group demonstrated mean performance in the filtered free recall response condition at 47.4% for the right ear and 39.7% for the left ear. Across these three groups of subjects, right ear performance was superior to left ear performance, and overall performance was roughly between 30% and 50 %. It is interesting to note that mean performance for the young adult subjects in the Dirks (1964) study was poorer than that of the probable APD group in the present study. This is somewhat surprising, given the auditory processing complaints reported by the subjects in the probable APD group in the present study, and given that no such complaints were reported in the Dirks (1964) study. However, due to the difference in goals of the present study and of the Dirks (1964) study, it is likely that Dirks (1964) did not feel that the auditory processing complaints, or lack thereof, of the young adult subjects in his study were relevant to the outcome. Poorer mean performance of the subjects in the Dirks (1964) study may also be due to the difference in filtering of the stimuli in each study. Dirks (1964) used stimuli low-pass filtered at 1000 Hz, whereas the present study used band-pass filtering from 892 Hz to 2521 Hz. The difference in acoustic information available across these sets of stimuli may account for differences in performance, therefore making direct comparison more challenging.

The present study hypothesized that the increased task difficulty introduced by filtering the dichotic stimuli would result in an increase in the REA as compared to the unfiltered condition for those individuals with auditory processing complaints. The results of the present study do not support this hypothesis. Instead, the finding that the magnitude of the REA was not significantly larger as a result of the filtering of the stimuli closely resembled the results of the Roup (2011) study. Roup (2011) found that for a group of normal-hearing young adults, mean performance on a dichotic word recognition task in quiet was 84.8% for the right ear and 80.1% for the left ear, with a mean REA of 3.3%. When noise was introduced to the dichotic word recognition task, in an effort to increase task difficulty and simulate peripheral hearing loss, performance decreased significantly. Mean performance on the dichotic speech in noise task was 51.5% for the right ear and 45.8% for the left ear. Despite this decrease in performance, the mean REA (5.9%) was not significantly different than the REA for the quiet dichotic speech recognition task (3.3%). Roup (2011) compared the performance of the young adult subjects on the dichotic speech in noise task to data from a previous study (Roup et al., 2006) regarding older adult performance on a similar dichotic speech recognition task in quiet. Roup (2011) found no significant difference in overall performance, indicating that the introduction of noise was sufficient to increase task difficulty and simulate peripheral hearing loss in the young adult group. Despite the lack of significant difference in overall performance, Roup (2011) found a significant difference in REA between the young adult and older adult groups, with older adults exhibiting a larger REA than the younger adult group. Roup (2011) concluded that the larger REA found in the older adult group was reflective of the auditory processing issues associated with aging in this population. Similarly, the current study hypothesized that an increase in REA in the filtered dichotic condition would reflect the subjective auditory processing complaints reported by subjects in the probable APD group. However, for the probable APD group, the REA in the unfiltered free recall response condition (10.9%) was actually larger than the REA in the filtered free recall response condition (7.7%). This finding is nearly opposite of that reported by Roup (2011), and does not support the hypothesis of the present study. Again, this lack of a significant finding is likely due to the large variability in ear advantage found in the probable APD group, as demonstrated in Figure 2.

An additional purpose of the present study was to determine if a modified version of the CHAPPS (Smoski, 1990) was sensitive to the auditory processing complaints of young adults. The results of the present study revealed that scores on the CHAPPS were significantly poorer for the group of subjects with auditory processing complaints as compared to the normal control group. The poorer performance on the CHAPPS for the probable APD group demonstrates the higher rate of auditory processing complaints reported by this group in comparison to the normal control group. The complaints identified by the CHAPPS, such as difficulty understanding speech in competitive listening environments and understanding verbally relayed information, reflect the auditory processing complaints generally reported by individuals considered “at-risk” for APD (AAA, 2010). These results support the idea that the CHAPPS can be used effectively with the young adult population as a tool for determining which individuals require further evaluation for APD. The collection of more normative data would be necessary to determine appropriate cutoffs for normal versus abnormal scores in this population. The finding that CHAPPS scores were significantly poorer for the probable APD group also supports the inclusion of these subjects in the present study, given that they should at least be considered at-risk for an auditory processing disorder (AAA, 2010).

Limitations of Current Study and Future Directions

The small number of subjects in each group may have contributed to the lack of certain significant findings in the present study. Repeating this study on a larger scale may help to determine whether any significant difference between these subject groups truly exists. Another option would be to repeat this study using various degrees of filtering to determine which type of filtering is most sensitive to auditory processing complaints in young adults. Finally, as noted above, collecting new normative data on the SCAN-3:A using young adults may help to redefine normal versus abnormal performance, making identification of APD more accurate in this population.

The variable performance of the probable APD group can also be seen as a limitation of the present study, as it is likely the reason no significant difference in performance was found between the probable APD group and normal control group. However, this is difficult to control for, as the general APD population itself is highly variable. This is evident when evaluating the various types of complaints reported by and associated with individuals with APD (AAA, 2010; Smoski, 1990)

Conclusions and Clinical Implications

The findings of the present study support the anecdotal evidence that auditory processing complaints in young adults may not be reflected by performance on the SCAN-3:A. This poses a significant issue for clinical audiologists who use test batteries such as the SCAN-3:A to diagnose auditory processing disorders and make appropriate treatment recommendations. It is hoped that future research will be conducted on a large scale to determine the appropriateness of the SCAN-3:A normative data for this population. In the interim, it is important that when faced with a young adult patient with auditory processing complaints but with normal scores on the SCAN-3:A to keep in mind that this test battery may not be appropriate for all patients. Regardless of the results of the SCAN-3:A, professionals should use appropriate counseling with this patient population, and suggest potential communication strategies that may help to alleviate perceived auditory processing issues. It should also be kept in mind that young adults who perform on the low end of normal or in the borderline range of the SCAN-3:A still demonstrate significantly poorer performance on this test battery than individuals without any auditory processing complaints, as indicated by the present study and by Keith (2009). As such, audiologists should use their own professional judgment, in conjunction with any other available auditory processing tests, in determining a diagnosis and treatment plan for these patients. Finally, the use of a screening tool (i.e., the CHAPPS) is crucial in determining the significance of the auditory processing complaints reported by patients. Collecting normative data using this screening tool within a given clinical setting may help the clinical audiologist to develop their own scoring cutoffs, making the use of the screening tool even more valuable. The overall message from the present study is that the use of the revised CHAPPS, a filtered dichotic listening task, or even the SCAN-3:A, should serve as only one part of an auditory processing test battery, rather than representing the entirety of the evaluation. Measuring the patient's performance across multiple measures of auditory processing will provide a more holistic and complete view of the patient's abilities, resulting in more precise diagnoses.

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Appendix A: Case History Questionnaire

SCREENING QUESTIONS

1) Do you have problems telling where a sound is coming from?

Never Seldom Occasionally Half the time Generally Almost always Always

2) Do you have a hard time hearing a specific person speaking to you in the presence of background noise?

Never Seldom Occasionally Half the time Generally Almost always Always

3) Do you have difficulty ignoring environmental sounds (i.e., newspaper rustling, refrigerator running) and
focusing on the primary message (i.e. someone speaking to you)?

Never Seldom Occasionally Half the time Generally Almost always Always

4) Do you feel you need spoken information repeated in order to understand the message?

Never Seldom Occasionally Half the time Generally Almost always Always

5) Do you have difficulty following spoken instructions?

Never Seldom Occasionally Half the time Generally Almost always Always

Appendix B: Revised CHAPPS Questionnaire

The subject should answer the following questions by comparing themselves to others of their age and background. For example, all people, to a certain extent, may have difficulties listening and understanding in a noisy room. These questions ask if the individual believes they do more poorly than the average listener in a given listening situation.

RESPONSE CHOICES
Less Difficulty: +1
Same Amount of Difficulty: 0
Slightly More Difficulty: -1
More Difficulty: -2
Considerably More Difficulty: -3
Significantly More Difficulty: -4
Cannot Function At All: -5

Listening Condition: NOISE – If listening in a room where there is background noise such as a TV set, music, others talking, children playing, etc., what is your level of difficulty hearing and understanding compared to the "average" individual?

1. When paying attention	+1	0	-1	-2	-3	-4	-5
2. When being asked a question	+1	0	-1	-2	-3	-4	-5
3. When being given simple instructions	+1	0	-1	-2	-3	-4	-5
4. When being given complicated, multiple instructions	+1	0	-1	-2	-3	-4	-5
5. When not paying attention	+1	0	-1	-2	-3	-4	-5
6. When involved with other activities	+1	0	-1	-2	-3	-4	-5
7. When listening in a group	+1	0	-1	-2	-3	-4	-5

Listening Condition: QUIET – If listening in a quiet room, what is your level of difficulty hearing and understanding compared to the "average" individual?

8. When paying attention	+1	0	-1	-2	-3	-4	-5
9. When being asked a question	+1	0	-1	-2	-3	-4	-5
10. When being given simple instructions	+1	0	-1	-2	-3	-4	-5
11. When being given complicated, multiple instructions	+1	0	-1	-2	-3	-4	-5
12. When not paying attention	+1	0	-1	-2	-3	-4	-5
13. When involved with other activities	+1	0	-1	-2	-3	-4	-5
14. When listening in a group	+1	0	-1	-2	-3	-4	-5

Listening Condition: IDEAL – When listening in a quiet room, no distractions, face-to-face and with good eye contact, what is your level of difficulty hearing and understanding compared to the "average" individual?

15. When being asked a question	+1	0	-1	-2	-3	-4	-5
16. When being given a simple instruction	+1	0	-1	-2	-3	-4	-5
17. When being given complicated, multiple instructions	+1	0	-1	-2	-3	-4	-5

Appendix B: Revised CHAPPS Questionnaire

Listening Condition: MULTIPLE INPUTS – When, in addition to listening, there is some other form of input (visual, tactile, etc.), what is your level of difficulty hearing and understanding compared to the "average" individual?

18. When listening and watching the speaker's face	+1	0	-1	-2	-3	-4	-5
19. When listening and reading material that is also being read out loud by another	+1	0	-1	-2	-3	-4	-5
20. When listening and watching someone provide an illustration such as a drawing, model, etc.	+1	0	-1	-2	-3	-4	-5

Listening Condition: AUDITORY MEMORY/SEQUENCING: If required to recall spoken information, what is your level of difficulty hearing and understanding compared to the "average" individual?

21. Immediately recalling information such as a word, spelling, number	+1	0	-1	-2	-3	-4	-5
22. Immediately recalling simple instructions	+1	0	-1	-2	-3	-4	-5
23. Immediately recalling multiple instructions	+1	0	-1	-2	-3	-4	-5
24. Not only recalling information, but also the order of sequence of the information	+1	0	-1	-2	-3	-4	-5
25. When delayed recollection (1 hour or more) of simple information (words, word spelling, numbers) is required	+1	0	-1	-2	-3	-4	-5
26. When delayed recollection (1 hour or more) of simple instructions is required	+1	0	-1	-2	-3	-4	-5
27. When delayed recollection (1 hour or more) of multiple instructions is required	+1	0	-1	-2	-3	-4	-5
28. When delayed recollection (24 hours or more) is required	+1	0	-1	-2	-3	-4	-5

Listening Condition: AUDITORY ATTENTION SPAN – If extended listening required, what level of difficulty is there in being attentive to what is being said?

29. When the listening time is less than 5 minutes	+1	0	-1	-2	-3	-4	-5
30. When listening time is 5 to 10 minutes	+1	0	-1	-2	-3	-4	-5
31. When listening time is over 10 minutes	+1	0	-1	-2	-3	-4	-5
32. When listening in a quiet room	+1	0	-1	-2	-3	-4	-5
33. When listening in a noisy room	+1	0	-1	-2	-3	-4	-5
34. When listening first thing in the morning	+1	0	-1	-2	-3	-4	-5
35. When listening at the end of the day, before supper time	+1	0	-1	-2	-3	-4	-5
36. When listening in a room where there are also visual distractions	+1	0	-1	-2	-3	-4	-5

Appendix C: Word lists adapted from Findlen & Roup (2011)

List One

	Right Ear	Left Ear
1	make	heat
2	peck	heal
3	bag	root
4	dike	hoop
5	lean	doze
6	bell	rose
7	loan	pen
8	toes	hag
9	comb	pad
10	boss	cop
11	cat	dean
12	pig	dot
13	pep	rig
14	cause	rice
15	dip	tame
16	sick	made
17	coat	loon
18	date	bed
19	moon	caught
20	pack	suit
21	meek	hid
22	keys	pick
23	time	rule
24	pal	rid
25	keep	dial

Appendix C: Word lists adapted from Findlen & Roup (2011)

List Two

	Right Ear	Left Ear
1	hope	come
2	mean	tag
3	maim	lice
4	deep	log
5	seal	mock
6	big	let
7	rot	dies
8	rake	sought
9	cod	soap
10	league	pass
11	ham	buys
12	call	lose
13	miss	rod
14	beg	dad
15	hog	toss
16	take	room
17	dawn	boom
18	hide	soon
19	peace	same
20	tomb	hiss
21	sip	mall
22	pope	hem
23	tote	mop
24	like	race
25	hall	load

Appendix C: Word lists adapted from Findlen & Roup (2011)

List Three

	Right Ear	Left Ear
1	tame	boss
2	rid	keys
3	caught	time
4	boom	dip
5	rose	pack
6	bed	heat
7	dot	beg
8	buys	seal
9	doze	ham
10	loon	sip
11	pope	hog
12	toes	hid
13	load	pal
14	rice	tag
15	log	keep
16	take	moon
17	come	big
18	race	sick
19	dies	rake
20	root	make
21	cod	tomb
22	pen	lean
23	mall	peck
24	coat	meek
25	let	hope

Appendix C: Word lists adapted from Findlen & Roup (2011)

List Four

	Right Ear	Left Ear
1	toss	hem
2	lice	rot
3	pad	soap
4	made	hide
5	mop	comb
6	dial	miss
7	hiss	pep
8	rig	dike
9	hag	loan
10	soon	like
11	cop	dawn
12	hoop	tote
13	rod	deep
14	dad	pig
15	call	date
16	pick	hall
17	rule	league
18	dean	bag
19	suit	bell
20	pass	room
21	lose	cat
22	same	cause
23	mock	sought
24	mean	peace
25	heal	maim

Appendix C: Word lists adapted from Findlen & Roup (2011)

List Five

	Right Ear	Left Ear
1	hope	big
2	caught	take
3	hem	pope
4	loan	sip
5	dip	boss
6	pal	rose
7	buys	mock
8	deep	miss
9	moon	time
10	load	pick
11	meek	toes
12	rice	league
13	pass	same
14	come	let
15	dike	beg
16	made	like
17	keep	rod
18	bed	call
19	dean	root
20	doze	heal
21	hoop	comb
22	soap	toss
23	hall	keys
24	lose	date
25	boom	pig

Appendix C: Word lists adapted from Findlen & Roup (2011)

List Six

	Right Ear	Left Ear
1	heat	bag
2	pack	sick
3	hog	pad
4	cat	make
5	race	soon
6	rig	cop
7	sought	dies
8	lice	rake
9	dial	log
10	hide	suit
11	hag	loon
12	room	mean
13	cause	peace
14	tomb	mop
15	tame	dawn
16	ham	seal
17	dad	hiss
18	maim	rot
19	pen	mall
20	dot	pep
21	tag	rule
22	lean	peck
23	tote	cod
24	hid	coat
25	rid	bell